# 12.E: Acids and Bases (Exercises)

## Exercises (Arrhenius Acids and Bases)

1. Define *Arrhenius acid*.
2. Define *Arrhenius base*.
3. What are some general properties of Arrhenius acids?
4. What are some general properties of Arrhenius bases?
5. Identify each substance as an Arrhenius acid, an Arrhenius base, or neither.
   a. NaOH
   b. $C_2H_5OH$
   c. $H_3PO_4$
6. Identify each substance as an Arrhenius acid, an Arrhenius base, or neither.
   a. $C_6H_{12}O_6$
   b. $HNO_2$
   c. $Ba(OH)_2$
7. Write the balanced chemical equation for the neutralization reaction between KOH and $H_2C_2O_4$. What is the salt?
8. Write the balanced chemical equation for the neutralization reaction between $Sr(OH)_2$ and $H_3PO_4$. What is the salt?
9. Write the balanced chemical equation for the neutralization reaction between HCl and $Fe(OH)_3$. What is the salt?
10. Write the balanced chemical equation for the neutralization reaction between $H_2SO_4$ and $Cr(OH)_3$. What is the salt?
11. $CaCl_2$ would be the product of the reaction of what acid and what base?
12. $Zn(NO_3)_2$ would be product of the reaction of what acid and what base?
13. $BaSO_4$ would be product of the reaction of what acid and what base?
14. $Na_3PO_4$ would be product of the reaction of what acid and what base?

### Answers

1. a compound that increases the $H^+$ concentration in water
3. sour taste, react with metals, and turn litmus red
5.
   a. Arrhenius base
   b. neither
   c. Arrhenius acid
7. $2KOH + H_2C_2O_4 \rightarrow 2H_2O + K_2C_2O_4$; $K_2C_2O_4$
9. $3HCl + Fe(OH)_3 \rightarrow 3H_2O + FeCl_3$; $FeCl_3$
11. HCl and $Ca(OH)_2$
13. $H_2SO_4$ and $Ba(OH)_2$

## Exercises (Brønsted-Lowry Acids and Bases)

1. Define *Brønsted-Lowry acid*. How does it differ from an Arrhenius acid?
2. Define *Brønsted-Lowry base*. How does it differ from an Arrhenius base?
3. Write the dissociation of hydrogen bromide in water as a Brønsted-Lowry acid-base reaction and identify the proton donor and proton acceptor.
4. Write the dissociation of nitric acid in water as a Brønsted-Lowry acid-base reaction and identify the proton donor and proton acceptor.
5. Pyridine ($C_5H_5N$) acts as a Brønsted-Lowry base in water. Write the hydrolysis reaction for pyridine and identify the Brønsted-Lowry acid and Brønsted-Lowry base.
6. The methoxide ion ($CH_3O^-$) acts as a Brønsted-Lowry base in water. Write the hydrolysis reaction for the methoxide ion and identify the Brønsted-Lowry acid and Brønsted-Lowry base.
7. Identify the Brønsted-Lowry acid and Brønsted-Lowry base in this chemical equation.

   $H_3PO_4 + OH^- \rightarrow H_2PO_4^- + H_2O$
8. Identify the Brønsted-Lowry acid and Brønsted-Lowry base in this chemical equation.

   $H_2C_2O_4 + 2F^- \rightarrow 2HF + C_2O_4^{2-}$
9. Predict the products of this reaction, assuming it undergoes a Brønsted-Lowry acid-base reaction.

   $HC_2H_3O_2 + C_5H_5N \rightarrow ?$
10. Predict the products of this reaction, assuming it undergoes a Brønsted-Lowry acid-base reaction.

    $(C_2H_5)_3N + H_2O \rightarrow ?$
11. What is the conjugate acid of $H_2O$? of $NH_3$?
12. What is the conjugate acid of $H_2PO_4^-$? of $NO_3^-$?
13. What is the conjugate base of $HSO_4^-$? of $H_2O$?
14. What is the conjugate base of $H_3O^+$? of $H_2SO_4$?
15. Identify the conjugate acid-base pairs in this reaction.

    $HSO_4^- + PO_4^{3-} \rightarrow SO_4^{2-} + HPO_4^{2-}$
16. Identify the conjugate acid-base pairs in this reaction.

    $HClO_3 + (C_2H_5)_3N \rightarrow ClO_3^- + (C_2H_5)_3NH^+$
17. Identify the conjugate acid-base pairs in this reaction.

    $NH_3 + C_6H_5O^- \rightarrow C_6H_5OH + NH_2^-$
18. Identify the conjugate acid-base pairs in this reaction.

    $C_5H_5NH^+ + C_2O_4^{2-} \rightarrow C_5H_5N + HC_2O_4^-$suming it undergoes a Brønsted-Lowry acid-base reaction.

### Answers

1. A Brønsted-Lowry acid is a proton donor. It does not necessarily increase the $H^+$ concentration in water.
3. $HBr + H_2O \rightarrow H_3O^+ + Br^-$; PD: HBr; PA: $H_2O$
5. $C_5H_5N + H_2O \rightarrow C_5H_5NH^+ + OH^-$; PD: $H_2O$; PA: $C_5H_5N$
7. BL acid: $H_3PO_4$; BL base: $OH^-$
9. $C_2H_3O_2^-$ and $C_5H_5NH^+$
11. $H_3O^+$; $NH_4^+$
13. $SO_4^{2-}$; $OH^-$

15. $HSO_4^-$ and $SO_4^{2-}$; $PO_4^{3-}$ and $HPO_4^{2-}$

17. $NH_3$ and $NH_2^-$; $C_6H_5O^-$ and $C_6H_5OH$

## Exercises (Acid-Base Titrations)

1. Define *titration*.
2. What is the difference between the titrant and the analyte?
3. True or false: An acid is always the titrant. Explain your answer.
4. True or false: An analyte is always dissolved before reaction. Explain your answer.
5. If 55.60 mL of 0.2221 M HCl was needed to titrate a sample of NaOH to its equivalence point, what mass of NaOH was present?
6. If 16.33 mL of 0.6664 M KOH was needed to titrate a sample of $HC_2H_3O_2$ to its equivalence point, what mass of $HC_2H_3O_2$ was present?
7. It takes 45.66 mL of 0.1126 M HBr to titrate 25.00 mL of $Ca(OH)_2$ to its equivalence point. What is the original concentration of the $Ca(OH)_2$ solution?
8. It takes 9.77 mL of 0.883 M $H_2SO_4$ to titrate 15.00 mL of KOH to its equivalence point. What is the original concentration of the KOH solution?

### Answers

1. a chemical reaction performed in a quantitative fashion

3. False; a base can be a titrant, or the reaction being performed may not even be an acid-base reaction.

5. 0.494 g

7. 0.1028 M

## Exercises (Strong and Weak Acids and Bases and their Salts)

1. Differentiate between a strong acid and a weak acid.
2. Differentiate between a strong base and a weak base.
3. Identify each as a strong acid or a weak acid. Assume aqueous solutions.
   a. HF
   b. HCl
   c. $HC_2O_4$
4. Identify each as a strong base or a weak base. Assume aqueous solutions.
   a. NaOH
   b. $Al(OH)_3$
   c. $C_4H_9NH_2$
5. Write a chemical equation for the ionization of each acid and indicate whether it proceeds 100% to products or not.
   a. $HNO_3$
   b. $HNO_2$
   c. $HI_3$
6. Write a chemical equation for the ionization of each base and indicate whether it proceeds 100% to products or not.
   a. $NH_3$
   b. $(CH_3)_3N$

c. $Mg(OH)_2$

7. Write the balanced chemical equation for the reaction of each acid and base pair.
   a. $HCl + C_5H_5N$
   b. $H_2C_2O_4 + NH_3$
   c. $HNO_2 + C_7H_9N$

8. Write the balanced chemical equation for the reaction of each acid and base pair.
   a. $H_3C_5H_5O_7 + Mg(OH)_2$
   b. $HC_3H_3O_3 + (CH_3)_3N$
   c. $HBr + Fe(OH)_3$

9. Identify each salt as neutral, acidic, or basic.
   a. NaBr
   b. $Fe(NO_3)_2$
   c. $Fe(NO_3)_3$

10. Identify each salt as neutral, acidic, or basic.
    a. $NH_4I$
    b. $C_2H_5NH_3Cl$
    c. KI

11. Identify each salt as neutral, acidic, or basic.
    a. $NaNO_2$
    b. $NaNO_3$
    c. $NH_4NO_3$

12. Identify each salt as neutral, acidic, or basic.
    a. $KC_2H_3O_2$
    b. $KHSO_4$
    c. $KClO_3$

13. Write the hydrolysis reaction that occurs, if any, when each salt dissolves in water.
    a. $K_2SO_3$
    b. KI
    c. $NH_4ClO_3$

14. Write the hydrolysis reaction that occurs, if any, when each salt dissolves in water.
    a. $NaNO_3$
    b. $CaC_2O_4$
    c. $C_5H_5NHCl$

15. When $NH_4NO_2$ dissolves in $H_2O$, both ions hydrolyze. Write chemical equations for both reactions. Can you tell if the solution will be acidic or basic overall?

16. When pyridinium acetate ($C_5H_5NHC_2H_3O_2$) dissolves in $H_2O$, both ions hydrolyze. Write chemical equations for both reactions. Can you tell if the solution will be acidic or basic overall?

17. A lab technician mixes a solution of 0.015 M $Mg(OH)_2$. Is the resulting $OH^-$ concentration greater than, equal to, or less than 0.015 M? Explain your answer.

18. A lab technician mixes a solution of 0.55 M $HNO_3$. Is the resulting $H^+$ concentration greater than, equal to, or less than 0.55 M? Explain your answer.

### Answers

1. A strong acid is 100% ionized in aqueous solution, whereas a weak acid is not 100% ionized.

3.

a. weak acid
b. strong acid
c. weak acid

5.

a. $HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$; proceeds 100%
b. $HNO_2(aq) \rightarrow H^+(aq) + NO_2^-(aq)$; does not proceed 100%
c. $HI_3(aq) \rightarrow H^+(aq) + I_3^-(aq)$; does not proceed 100%

7.

a. $HCl + C_5H_5N \rightarrow Cl^- + C_5H_5NH^+$
b. $H_2C_2O_4 + 2NH_3 \rightarrow C_2O_4^{2-} + 2NH_4^+$
c. $HNO_2 + C_7H_9N \rightarrow NO_2^- + C_7H_9NH^+$

9.

a. neutral
b. acidic
c. acidic

11.

a. basic
b. neutral
c. acidic

13.

a. $SO_3^{2-} + H_2O \rightarrow HSO_3^- + OH^-$
b. no reaction
c. $NH_4^+ + H_2O \rightarrow NH_3 + H_3O^+$

15. $NH_4^+ + H_2O \rightarrow NH_3 + H_3O^+$; $NO_2^- + H_2O \rightarrow HNO_2 + OH^-$ ; it is not possible to determine whether the solution will be acidic or basic.

17. greater than $0.015 M$ because there are two $OH^-$ ions per formula unit of $Mg(OH)_2$

## Exercise (Autoionization of Water)

1. Does $[H^+]$ remain constant in all aqueous solutions? Why or why not?
2. Does $[OH^-]$ remain constant in all aqueous solutions? Why or why not?
3. What is the relationship between $[H^+]$ and $K_w$? Write a mathematical expression that relates them.
4. What is the relationship between $[OH^-]$ and $K_w$? Write a mathematical expression that relates them.
5. Write the chemical equation for the autoionization of water and label the conjugate acid-base pairs.
6. Write the reverse of the reaction for the autoionization of water. It is still an acid-base reaction? If so, label the acid and base.

7. For a given aqueous solution, if $[H^+] = 1.0 \times 10^{-3}$ M, what is $[OH^-]$?
8. For a given aqueous solution, if $[H^+] = 1.0 \times 10^{-9}$ M, what is $[OH^-]$?
9. For a given aqueous solution, if $[H^+] = 7.92 \times 10^{-5}$ M, what is $[OH^-]$?
10. For a given aqueous solution, if $[H^+] = 2.07 \times 10^{-11}$ M, what is $[H^+]$?
11. For a given aqueous solution, if $[OH^-] = 1.0 \times 10^{-5}$ M, what is $[H^+]$?
12. For a given aqueous solution, if $[OH^-] = 1.0 \times 10^{-12}$ M, what is $[H^+]$?
13. For a given aqueous solution, if $[OH^-] = 3.77 \times 10^{-4}$ M, what is $[H^+]$?
14. For a given aqueous solution, if $[OH^-] = 7.11 \times 10^{-10}$ M, what is $[H^+]$?
15. What are $[H^+]$ and $[OH^-]$ in a 0.344 M solution of $HNO_3$?
16. What are $[H^+]$ and $[OH^-]$ in a 2.86 M solution of HBr?
17. What are $[H^+]$ and $[OH^-]$ in a 0.00338 M solution of KOH?
18. What are $[H^+]$ and $[OH^-]$ in a $6.02 \times 10^{-4}$ M solution of $Ca(OH)_2$?
19. If $HNO_2$ is dissociated only to an extent of 0.445%, what are $[H^+]$ and $[OH^-]$ in a 0.307 M solution of $HNO_2$?
20. If $(C_2H_5)_2NH$ is dissociated only to an extent of 0.077%, what are $[H^+]$ and $[OH^-]$ in a 0.0955 M solution of $(C_2H_5)_2NH$?

## Answers

1. $[H^+]$ varies with the amount of acid or base in a solution.
3. $$[H^+] = \frac{K_W}{[OH^-]} \quad (12.E.1)$$
5. $H_2O + H_2O \rightarrow H_3O^+ + OH^-$; $H_2O/H_3O^+$ and $H_2O/OH^-$
7. $1.0 \times 10^{-11}$ M
9. $1.26 \times 10^{-10}$ M
11. $1.0 \times 10^{-9}$ M
13. $2.65 \times 10^{-11}$ M
15. $[H^+] = 0.344$ M; $[OH^-] = 2.91 \times 10^{-14}$ M
17. $[OH^-] = 0.00338$ M; $[H^+] = 2.96 \times 10^{-12}$ M
19. $[H^+] = 0.00137$ M; $[OH^-] = 7.32 \times 10^{-12}$ M

Exercises (The pH Scale)

1. Define *pH*. How is it related to pOH?
2. Define *pOH*. How is it related to pH?
3. What is the pH range for an acidic solution?
4. What is the pH range for a basic solution?
5. What is $[H^+]$ for a neutral solution?
6. What is $[OH^-]$ for a neutral solution? Compare your answer to Exercise 6. Does this make sense?
7. Which substances in Table 12.7.1 are acidic?
8. Which substances in Table 12.7.1 are basic?
9. What is the pH of a solution when $[H^+]$ is $3.44 \times 10^{-4}$ M?

10. What is the pH of a solution when $[H^+]$ is $9.04 \times 10^{-13}$ M?
11. What is the pH of a solution when $[OH^-]$ is $6.22 \times 10^{-7}$ M?
12. What is the pH of a solution when $[OH^-]$ is 0.0222 M?
13. What is the pOH of a solution when $[H^+]$ is $3.44 \times 10^{-4}$ M?
14. What is the pOH of a solution when $[H^+]$ is $9.04 \times 10^{-13}$ M?
15. What is the pOH of a solution when $[OH^-]$ is $6.22 \times 10^{-7}$ M?
16. What is the pOH of a solution when $[OH^-]$ is 0.0222 M?
17. If a solution has a pH of 0.77, what is its pOH, $[H^+]$, and $[OH^-]$?
18. If a solution has a pOH of 13.09, what is its pH, $[H^+]$, and $[OH^-]$?

### Answers

1. pH is the negative logarithm of $[H^+]$ and is equal to 14 − pOH.
3. pH < 7
5. $1.0 \times 10^{-7}$ M
7. Every entry above pure water is acidic.
9. 3.46
11. 7.79
13. 10.546.21
15. pOH = 13.23; $[H^+] = 1.70 \times 10^{-1}$ M; $[OH^-] = 5.89 \times 10^{-14}$ M

## Exercises (Buffers)

1. Define *buffer*. What two related chemical components are required to make a buffer?
2. Can a buffer be made by combining a strong acid with a strong base? Why or why not?
3. Which combinations of compounds can make a buffer? Assume aqueous solutions.
   a. HCl and NaCl
   b. $HNO_2$ and $NaNO_2$
   c. $NH_4NO_3$ and $HNO_3$
   d. $NH_4NO_3$ and $NH_3$
4. Which combinations of compounds can make a buffer? Assume aqueous solutions.
   a. $H_3PO_4$ and $Na_3PO_4$
   b. $NaHCO_3$ and $Na_2CO_3$
   c. $NaNO_3$ and $Ca(NO_3)_2$
   d. $HN_3$ and $NH_3$
5. For each combination in Exercise 3 that is a buffer, write the chemical equations for the reactions of the buffer components when a strong acid and a strong base is added.
6. For each combination in Exercise 4 that is a buffer, write the chemical equations for the reactions of the buffer components when a strong acid and a strong base is added.
7. The complete phosphate buffer system is based on four substances: $H_3PO_4$, $H_2PO_4^-$, $HPO_4^{2-}$, and $PO_4^{3-}$. What different buffer solutions can be made from these substances?
8. Explain why NaBr cannot be a component in either an acidic or a basic buffer.

9. Two solutions are made containing the same concentrations of solutes. One solution is composed of $H_3PO_4$ and $Na_3PO_4$, while the other is composed of HCN and NaCN. Which solution should have the larger capacity as a buffer?

10. Two solutions are made containing the same concentrations of solutes. One solution is composed of $NH_3$ and $NH_4NO_3$, while the other is composed of $H_2SO_4$ and $Na_2SO_4$. Which solution should have the larger capacity as a buffer?

### Answers

1. A buffer is the combination of a weak acid or base and a salt of that weak acid or base.

3.

a. no
b. yes
c. no
d. yes

5. 3b: strong acid: $NO_2^- + H^+ \rightarrow HNO_2$ ; strong base: $HNO_2 + OH^- \rightarrow NO_2^- + H_2O$ ; 3d: strong base: $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$ ; strong acid: $NH_3 + H^+ \rightarrow NH_4^+$

7. Buffers can be made from three combinations: (1) $H_3PO_4$ and $H_2PO_4^-$, (2) $H_2PO_4^-$ and $HPO_4^{2-}$, and (3) $HPO_4^{2-}$ and $PO_4^{3-}$. (Technically, a buffer can be made from any two components.)

9. The phosphate buffer should have the larger capacity.

## Additional Exercises

1. Write the balanced chemical equation between Zn metal and $HCl(aq)$. The other product is $ZnCl_2$.

2. Write the neutralization reaction in which $ZnCl_2$, also found in Exercise 1, is the salt product.

3. Why isn't an oxide compound like CaO considered a salt? (Hint: what acid-base combination would be needed to make it if it were a salt?)

4. Metal oxides are considered basic because they react with $H_2O$ to form OH compounds. Write the chemical equation for a reaction that forms a base when $CaO$ is combined with $H_2O$.

5. Write the balanced chemical equation between aluminum hydroxide and sulfuric acid.

6. Write the balanced chemical equation between phosphoric acid and barium hydroxide.

7. Write the equation for the chemical reaction that occurs when caffeine $(C_8H_{10}N_4O_2)$ acts as a Brønsted-Lowry base.

8. Citric acid $(C_6H_8O_7)$ is the acid found in citrus fruits. It can lose a maximum of three $H^+$ ions in the presence of a base. Write the chemical equations for citric acid acting stepwise as a Brønsted-Lowry acid.

9. Can an amphiprotic substance be a strong acid and a strong base at the same time? Explain your answer.

10. Can an amphiprotic substance be a weak acid and a weak base at the same time? If so, explain why and give an example.

11. Under what conditions will the equivalence point of a titration be slightly acidic?

12. Under what conditions will the equivalence point of a titration be slightly basic?

13. Write the chemical equation for the autoionization of $NH_3$.

14. Write the chemical equation for the autoionization of HF.

15. What is the $\mathrm{pOH}$ range for an acidic solution?

16. What is the pOH range for a basic solution?

17. The concentration of commercial $\mathrm{HCl}$ is about $12\mathrm{M}$. What is its $\mathrm{pH}$ and $\mathrm{pOH}$ ?

18. The concentration of concentrated $\mathrm{H_2SO_4}$ is about 18 M. Assuming only one $\mathrm{H^+}$ comes off the $\mathrm{H_2SO_4}$ molecule, what is its $\mathrm{pH}$ and $\mathrm{pOH}$ ? What would the $\mathrm{pH}$ and pOH be if the second $\mathrm{H^+}$were also ionized?

## Answers

1. $\mathrm{Zn + 2HCl \rightarrow ZnCl_2 + H_2}$

3. The $\mathrm{O^{2-}}$ ion would come from $\mathrm{H_2O}$, which is not considered a classic acid in the Arrhenius sense.

5. $\mathrm{2Al(OH)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6H_2O}$

7. $\mathrm{C_8H_{10}\,N_4O_2 + H_2O \rightarrow C_8H_{10}\,N_4O_2H^+ + OH^-}$ ; the $\mathrm{H^+}$ion attaches to one of the $\mathrm{N}$ atoms in the caffeine molecule.

9. As a strong acid or base, an amphiprotic substance reacts $100\%$ as an acid or a base, so it cannot be a base or an acid at the same time.

11. if the salt produced is an acidic salt

13. $\mathrm{NH_3 + NH_3 \rightarrow NH_4^+ + NH_2^-}$

15. $\mathrm{pOH} > 7$

17. $\mathrm{pH} = -1.08; \mathrm{pOH} = 15.08$